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HAZARDOUS CHEMICAL PUMP TESTS.(U)
JUL 80 S J ROSENBERG, R F CHRISTENSEN
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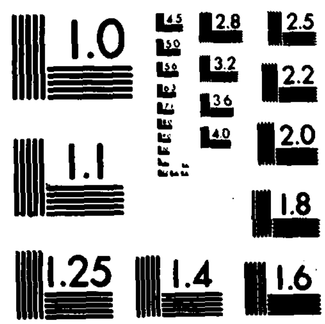

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10 Steven J. ROSENBERG ~~and~~ Roger F. CHRISTENSEN

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16. Abstract

Three hydraulically powered submersible centrifugal pumps, the Framo TK-4, Framo TK-5 and Thune Eureka 150, were tested to document their performance in pumping viscous liquids. The tests were performed using an ADAPTS 40 HP prime mover or a NAVSEA 80 HP prime mover under controlled viscosity (temperature) and discharge pressure to simulate the various hazardous chemicals and long discharge lines expected during the offloading of stricken vessels. All three pumps performed adequately under the test conditions. In particular, the Framo TK-5 can provide a greater discharge flow rate than the Framo TK-4 under the same test conditions. The Framo TK-5 performed well with the ADAPTS prime mover. Both the Framo TK-5 and the Thune Eureka 150 pumps performed well with the NAVSEA prime mover. The NAVSEA prime mover has the capability to operate two Framo TK-5 pumps simultaneously. The results will be used to help in preparing procurement specifications for a Coast Guard hazardous chemical pumping system.

17. Key Words

HAZARDOUS CHEMICAL DISCHARGE AMELIORATION, PUMPING EQUIPMENT, VISCOUS FLOW, TRANSFER, TESTS, HYDRAULIC EQUIPMENT, HAZARDOUS CHEMICAL OFFLOADING EQUIPMENT

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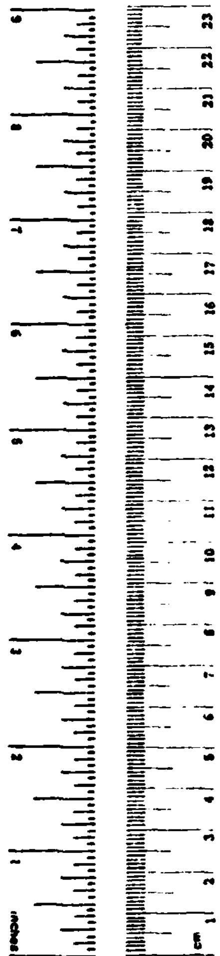
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

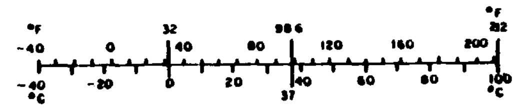
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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GLOSSARY OF SYMBOLS

Symbol	Meaning	Units
H_t	Total pump head	ft_{H2O}, psi
P	Pressure	psi
γ	Specific weight	lbs/ft^3
V	Velocity	ft/sec
Z	Height	ft
g	Gravitational constant	32.2 ft/sec^2
Q	Volume flow rate	gal/min
t	Time	min
N	Speed	rev/min
M	Mass flow rate	lb/sec
T	Torque	lbs-ft
D	Displacement	in^3
A	Area	in^2

Subscripts

Hyd	Hydraulic
i	Inlet
d	Discharge
w	Pumped fluid

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1.0 BACKGROUND

The Hazardous Chemical Discharge Prevention and Reduction Project is one of six projects in the Coast Guards program area of Hazardous Chemical Discharge Amelioration which has the ultimate objective of developing equipment and methods for responding to discharges of hazardous chemicals into the waters of the U.S.

Specifically, this project is tasked with the investigation and development of equipment and methods to prevent hazardous chemical discharge from an endangered marine vessel and to stop or reduce the discharge from a marine transport container which is already leaking. It is intended that the end user of the hardware developed will be Coast Guard pollution response personnel.

One of the project objectives is the development of a light-weight hazardous chemical off-loading system. In conjunction with this objective, tests were conducted on commercially available submersible centrifugal pumps to document their performance and as an aid in developing a procurement specification for a hazardous chemical pumping system.

This report documents the results of the testing program.

2.0 OBJECTIVE

The objective of this program was to document the performance of the Framo TK-4, and TK-5 pumps as well as the Thune-Eureka 150 pump in pumping liquids of various viscosities with the ADAPTS (Air Deployable Anti-Pollution Transfer System) and NAVSEA (Naval Sea Systems Command) prime mover. The Thune-Eureka 150 pump and the NAVSEA prime mover constitutes the U.S. Coast Guard viscous oil pumping system (VOPS). Extra emphasis was placed on the comparison of the Framo TK-4 and TK-5 operating off an ADAPTS prime mover. The data generated for the Framo pumps will be used to help in preparing procurement specifications. The scheduled pump tests are indicated in Table 1.

Water and #4 fuel oil were used as "simulants" for hazardous chemicals. Water was used to provide a test fluid with a viscosity of 1 centistoke (cS) while the #4 fuel oil provided a test fluid with a viscosity of 110-120 cS*.

Table 1
Scheduled Pump Tests

	Framo TK-4		Framo TK-5		Thune-Eureka 150	
Fluid Pumped	ADAPTS 40 HP	NAVSEA 80 HP	ADAPTS 40 HP	NAVSEA 80 HP	ADAPTS 40 HP	NAVSEA 80 HP
Fresh Water		X	X	X	X	
#4 Fuel Oil (110-120 cS)			X	X	X	X

* A viscosity of 110-120 cS was chosen as an upper limit for these tests as it encompasses more than 75% of the CHRIS liquid chemicals shipped in bulk.

3.0 EQUIPMENT AND SYSTEM DESCRIPTION

The pump tests were conducted by R&D Center and Strike Team personnel during the period of 7-18 January 1980 at the Naval Coastal Systems Center (NCSC), Panama City, Florida. As a result of previous work, NCSC has a non-propelled yard oiler, YON-284, with storage tank heating and cooling capabilities (30°F to 110°F). This enables the viscosity of the fluid to be regulated (See Appendix A). The test system contains two subsystems, the hydraulic system and the pump system, which are connected by a common shaft at the pump.

3.1 The Hydraulic System

The hydraulic system consists of two major components; the hydraulic prime mover and the hydraulic motor driving the pump. These two components are connected by two (2) one-inch hydraulic hoses, one supply and one return. The hydraulic supply and return pressures were monitored at the pump motor for the oil tests and at the prime mover for the water tests. The flow was measured by a dynamic flow meter in the return line to the prime mover. The hydraulic system arrangement is shown in Figure 1.

3.2 The Pumping System

The pumping system consisted of the pump and a manifold constructed to direct the flow of the pumped fluid. The manifold used for the TK-5, and VOPS pumps was made of six-inch steel piping. The discharge head pressures were regulated by the use of a six-inch gate valve. The TK-4 pump used a four-inch steel manifold with a four-inch gate valve. The pump discharge pressure was sensed at the discharge of the pump and read remotely. The tank level was obtained using a flotation gauge except when pumping #6 fuel oil where it was measured by sounding the tank. The arrangement of the pumping system is shown in Figure 1.

DIAGRAM OF TEST SYSTEM

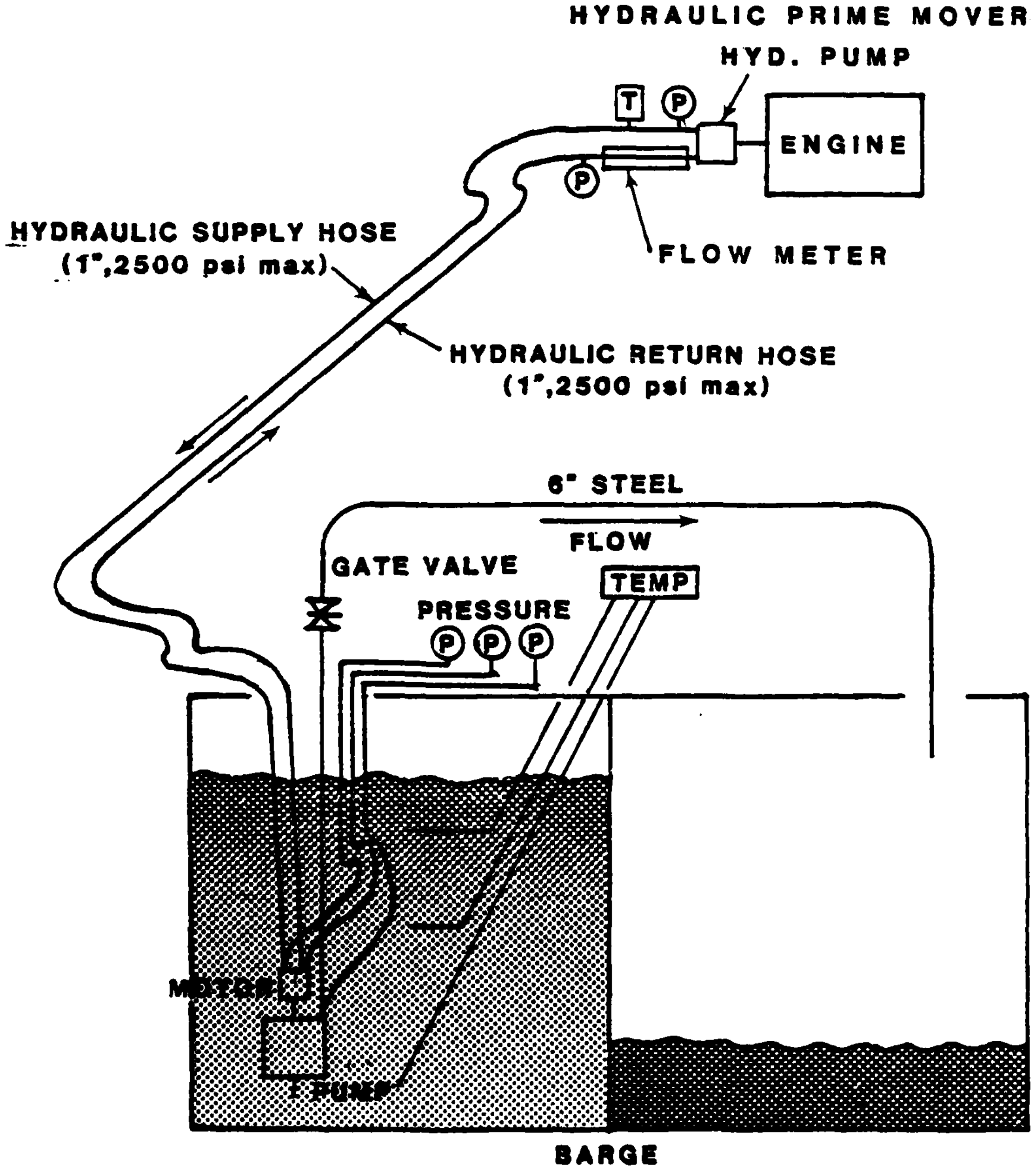

FIGURE 1

4.0 RESULTS

4.1 Pump Characteristics

Pump performance characteristics are generally shown as a plot of the pump head versus the pump flow rate at a constant speed. The raw test data (Appendix B) was corrected for various constant speeds and used to calculate the pump head and the pump flow rate. The raw data was reduced in the following manner.

4.1.1 Pump Head

The total pump head (H_T) is a measure of the energy imparted to the fluid being pumped. By applying Bernoullis' Theorem, the total pump head is found to be the following:

$$H_T = \frac{P_d}{\gamma_d} - \frac{P_i}{\gamma_i} + \frac{\overline{V}_d^2 - \overline{V}_i^2}{2g} + Z_d - Z_i$$

This relationship may be simplified by making the following assumptions:

1. The fluid specific weight (γ) is constant through the pump. $\gamma_d = \gamma_i$
2. The difference in height (Z) between the inlet and discharge of the pump is negligible. $Z_d - Z_i = 0$
3. The effect of increased velocity is much less than that of increased pressure through the pump.

$$\frac{V_d^2 - V_i^2}{2g} \ll \frac{P_d}{\gamma} - \frac{P_i}{\gamma}$$

4. The change in pressure ($P_d - P_i$) across the pump is equal to the discharge pressure of the pump.

These assumptions reduce the equation for the total pump head to the following:

$$H_T = \frac{P_d}{\gamma}$$

For simplicity, the pump head will be plotted in pounds per square inch (psi).

4.1.2 Pump Flow Rate

The pump flow rate (Qw) of the pump was derived from the measured quantity of water pumped over a measured period of time (t). The dimensions of the tank are such that a liquid level change of one inch is equal to 318 gallons. The following relationship exists:

$$Qw = 318 \frac{(\text{inches pumped})}{t}$$

4.1.3 Pump Speed

The pump performance is plotted at a constant pump speed; however, the pump tests were not conducted at a constant pump speed. This means that the raw test data must be corrected to the desired pump speed. This was done by applying the following relationships from the Hydraulic Institute Standards[1]

$$\text{Pump Capacity} \quad Q_{W2} = \frac{N_2}{N_1} \quad Q_{W1}$$

$$\text{Pump Head} \quad Hp_2 = \frac{N_2}{N_1}^{2} \; Hp_1$$

where, N_1 = the test pump speed
N_2 = the desired pump speed
Q_{W1} = the test pump flow rate
Q_{W2} = the corrected pump flow rate
Hp_1 = the test pump head
Hp_2 = the corrected pump head

During the pump tests, the pump speed was not monitored but the hydraulic flow rate was. The hydraulic flow rate is the product of the pump speed and the pump displacement. The pump displacement for each respective pump was constant throughout the pump test. From this, it can be deduced that the ratio of the rated pump speed (N_2) to the test pump speed (N_1) is equivalent to the ratio of the rated hydraulic flow rate (Q_{HYD2}) to the test hydraulic flow rate (Q_{HYD1}), or,

$$\frac{N_2}{N_1} = \frac{Q_{HYD2}}{Q_{HYD1}}$$

By substitution of the hydraulic flow rate ratio for the pump speed ratio, the raw test data may be corrected for speed by applying the following:

$$\text{Pump Capacity} \quad Q_{W2} = \frac{Q_{HYD2}}{Q_{HYD1}} \quad Q_{W1}$$

$$\text{Pump Head} \quad Hp_2 = \frac{Q_{HYD2}}{Q_{HYD1}}^{2} \; Hp_1$$

The pump performance is plotted for various constant speeds. These speeds were chosen to coincide with the speeds used by the manufacturer, and hydraulic flow limitations of the hydraulic prime movers.

4.1.4 Pump Characteristic Curves

Figures 2 through 11, are the resulting pump characteristic curves for the pumps tested*. The pump, hydraulic prime mover,

* Figures 2 and 3 were generated from previous Framo TK-4 pump test data.[2]

and fluid pumped are indicated in the upper right corner of the figure for each test. The constant pump speed is indicated on each characteristic curve. The data used for determining the pump characteristic curves appears below each respective figure. It should be noted that the resulting pump characteristic curves are independent of the prime mover used. The dashed line in each of the figures indicates the maximum pump performance as limited by one specific hydraulic prime mover used in the test. This will be discussed further in the next section.

4.2 Hydraulic Prime Mover

The capabilities of the hydraulic prime mover may limit the pump performance. The hydraulic prime mover limits the power, hydraulic flow rate, and hydraulic pressure available to the pump motor. Table 2 indicates the limits imposed by the prime movers used during these tests. The maximum pump speed, that can be obtained with a given prime mover, is determined by the displacement of each respective pump motor and the hydraulic flow provided (see section 4.1.3). The maximum rated speed for each respective pump with the prime movers used during these tests is indicated in table 2.

In order to bring the pump up to the rated speed, the pump motor must be capable of supplying more torque than is required by the pump impeller. If the pump motor is assumed to be 100% efficient in transmitting power, the following relationship is found to exist.

$$\frac{Q\Delta P}{1,714} = \frac{2\pi NT}{33,000}$$

where
Q = hydraulic flow - gpm
ΔP = pressure change across pump motor - psi
N = pump speed - rpm
T = torque - ft lbs
π = 3.1416

By substituting the product of pump speed and pump displacement for the hydraulic flow rate ($Q=ND$) in the above relationship, it is found that the torque is directly proportional to the displacement and pressure drop across the pump motor. From this it should be recognized that the pressure, or power, available can further limit the maximum speed that the pump may obtain. This limitation on the pump speed can not be directly determined because of the efficiencies encountered when transmitting the power from the prime mover to the work done by the pump. It was not within the scope of this test to evaluate the hydraulic prime mover and its efficiency of power transmission.

A dashed line estimating the maximum pump operation, as limited by the hydraulic prime mover, is indicated on figures 2 through 11. In all the pump tests, the prime mover was operated at its maximum capacity except where limited by the pump design. The only test where the prime mover operation was limited by the pump design occurred in the Framo TK-4, NAVSEA 80 HP test. In all other tests, the pump operation was limited by the maximum power, hydraulic flow rate or hydraulic pressure available from the hydraulic prime mover.

Table 2
Hydraulic Prime Mover Limitations

	ADAPTS 40	NAVSEA 80
Maximum hydraulic flow (gpm)	29.2	52
Maximum hydraulic pressure (psi)	2200	2500
Maximum power (hp)	40	87
Maximum rated pump speed (rpm)		
FRAMO TK-4 (Vickers 25M42A)	2360	3200*
FRAMO TK-4 (Vickers 25M55A)	1918	3415
FRAMO TK-5	3946	4750*
EUREKA 150	1555	2770

* Maximum design Pump Speed specified by manufacturer

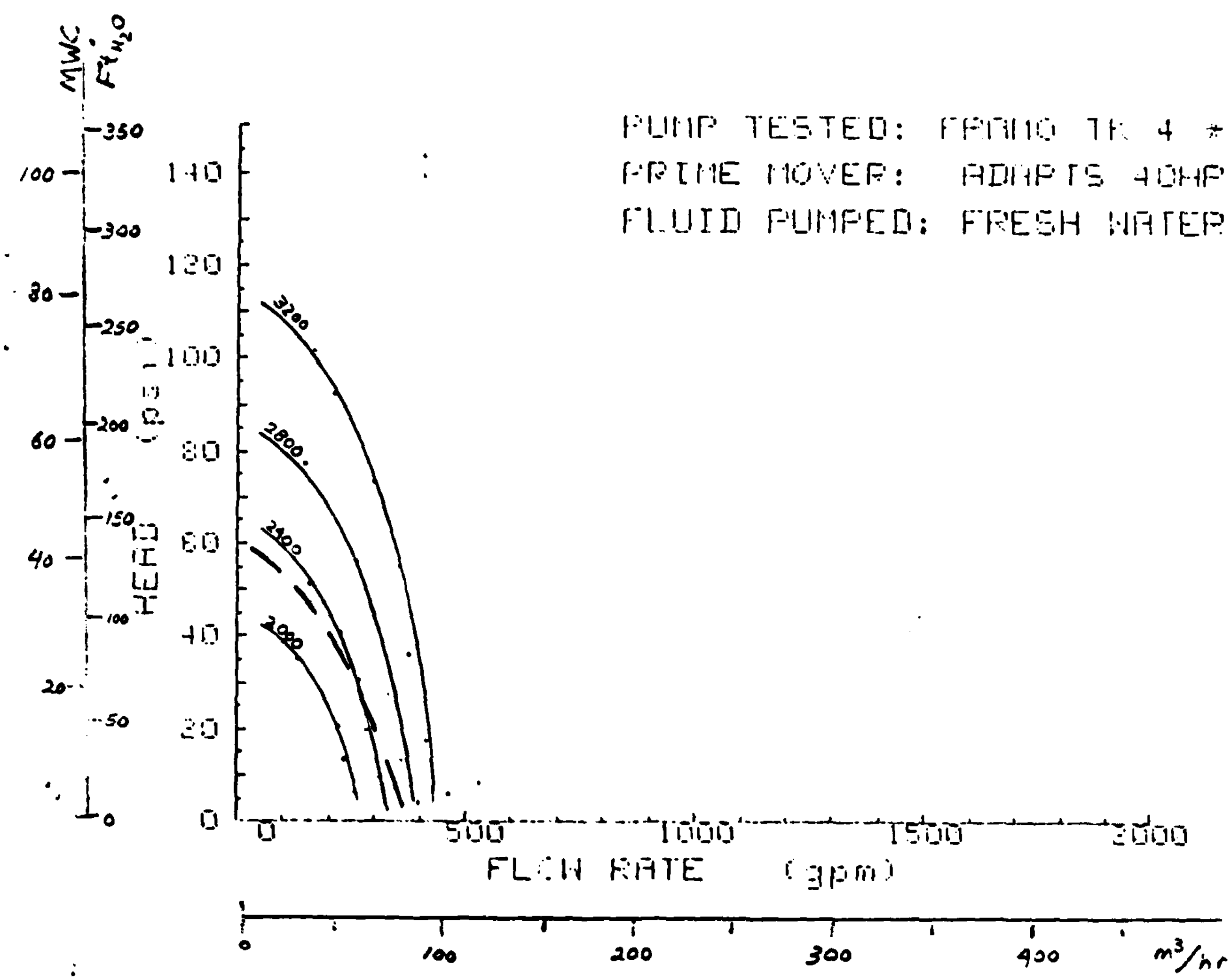

FIGURE 2

TEST **			2000 RPM Qhydx 24.7		2400 RPM Qhydx 29.7		2800 RPM Qhydx 34.6		3200 RPM Qhydx 39.6	
Qhyd gpm	Qu gpm	Hp psi	Qux gpm	Hpx psi	Qux gpm	Hpx psi	Qux gpm	Hpx psi	Qux gpm	Hpx psi
29.0	389.0	5.0	331.3	3.6	395.4	5.2	464.1	7.1	531.2	9.3
29.0	304.0	10.0	258.9	7.3	311.3	10.5	362.7	[illegible]	415.1	18.6
29.0	277.0	20.0	235.9	14.5	283.7	21.0	330.5	28.5	378.2	37.3
29.0	260.0	30.0	221.4	21.8	266.3	31.5	310.2	42.7	355.0	55.9
29.0	219.0	40.0	186.5	29.0	224.3	42.0	261.3	56.9	299.0	74.6
29.0	154.0	50.0	131.2	36.3	157.7	52.4	183.7	71.2	210.3	93.2
29.0	122.0	55.0	103.9	39.9	124.9	57.7	145.6	78.3	166.6	102.6

* FRAMO TK 4 WITH VICKERS 25M42A-1C20 HYDRAULIC MOTOR
** DATA FROM PREVIOUS FRAMO TK 4 PUMP TEST

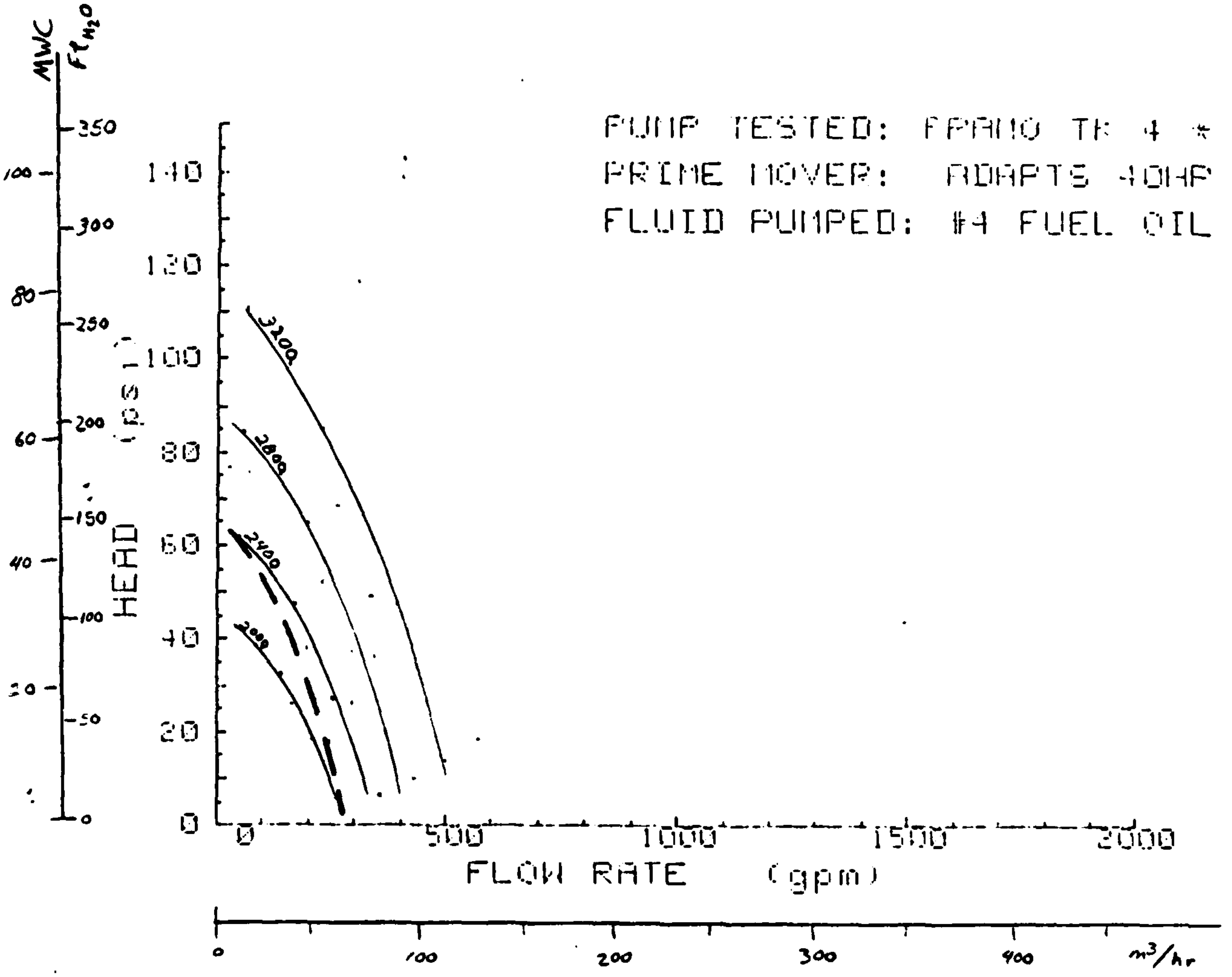

FIGURE 3

TEST **			2000 RPM Qhydx 24.7		2400 RPM Qhydx 29.7		2800 RPM Qhydx 34.6		3200 RPM Qhyd 39.6	
Qhyd gpm	Qw gpm	Hp psi	Qwx gpm	Hpx psi	Qwx gpm	Hpx psi	Qwx gpm	Hpx psi	Qwx gpm	Hp psi
21.0	318.0	6.0	357.0	7.6	429.3	10.9	500.1	14.8	572.4	19.4
22.0	219.0	15.0	245.9	18.9	295.7	27.3	344.4	37.4	394.2	48.6
25.0	214.0	20.0	211.4	19.5	254.2	28.2	296.2	39.3	339.0	50.2
26.0	174.0	30.0	165.3	27.1	198.8	39.1	231.6	53.1	265.0	69.0
27.0	156.0	40.0	142.7	33.5	171.6	48.4	199.9	65.7	228.8	86.0
25.0	113.0	50.0	99.7	38.9	119.9	56.3	139.6	76.3	159.8	100.0
29.0	48.0	60.0	40.9	43.5	49.2	62.9	57.3	85.4	65.5	111.9

* FRAMO TK 4 WITH VICKERS 25M42A-1C20 HYDRAULIC MOTOR
** DATA FROM PREVIOUS FRAMO TK 4 PUMP TEST

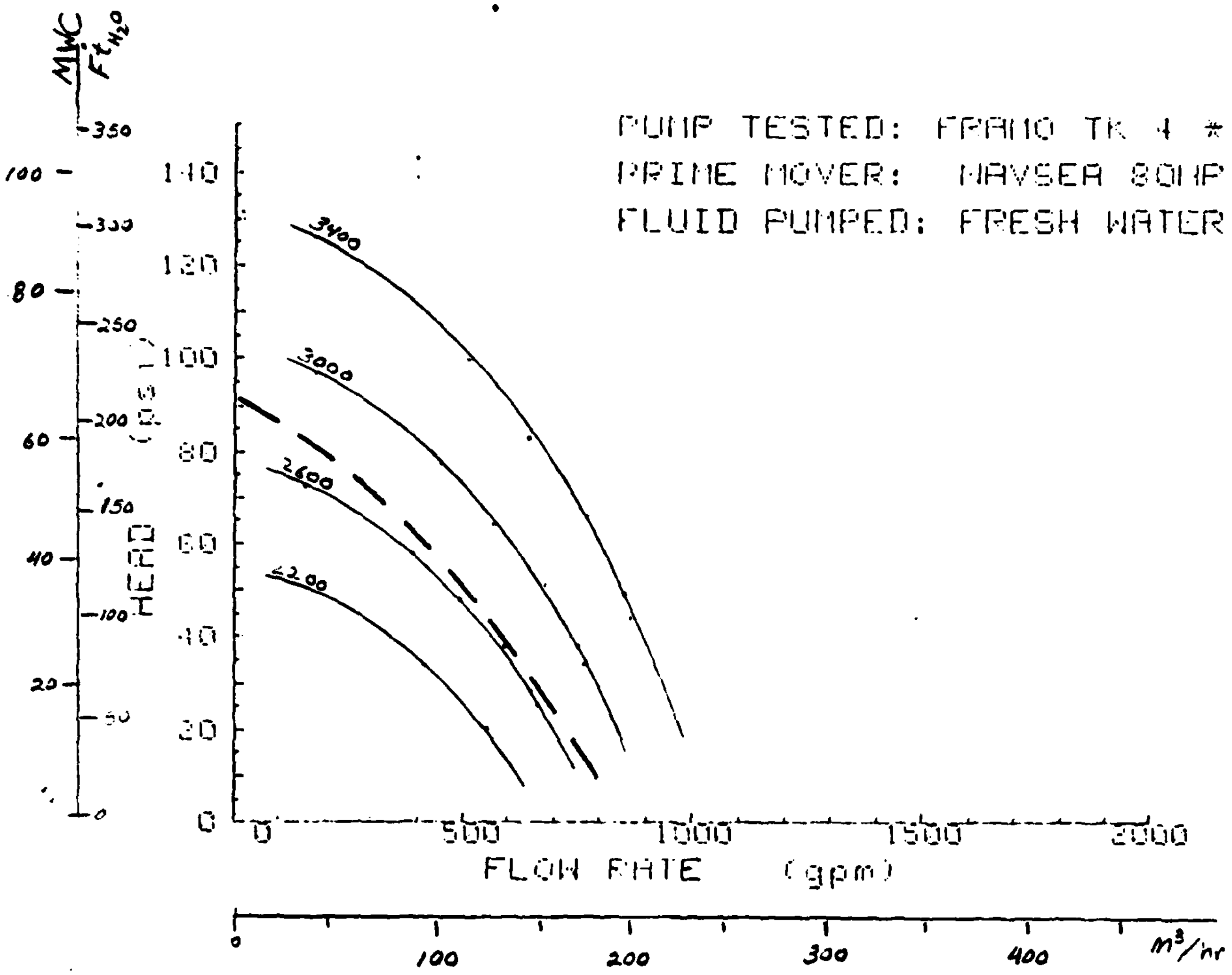

FIGURE 4

TEST — — —			2200 RPM Qhydx 33.5		2600 RPM Qhydx 39.6		3000 RPM Qhydx 45.7		3400 RPM Qhyd 51.8	
Qhyd gpm	Qw gpm	Hp psi	Qwx gpm	Hpx psi	Qwx gpm	Hpx psi	Qwx gpm	Hpx psi	Qwx gpm	Hpx psi
40.0	671.6	27.0	562.5	18.9	664.9	26.5	767.3	35.2	869.7	45.3
40.0	660.5	30.0	553.2	21.0	653.9	29.4	754.6	[illegible]	855.3	50.3
40.0	598.5	40.0	501.2	28.1	592.5	39.2	683.8	52.2	775.1	67.1
40.0	497.2	50.0	417.2	35.1	493.2	49.0	569.2	65.3	645.2	83.9
40.0	396.3	60.0	332.3	42.1	392.8	58.8	453.3	78.3	513.9	100.6
40.0	159.3	75.0	133.4	52.6	157.7	73.5	182.0	97.9	206.3	125.8

SHUT OFF HEAD 55psi

* FRAMO TK 4 WITH VICKERS 25M55A-1C20 HYDRAULIC MOTOR

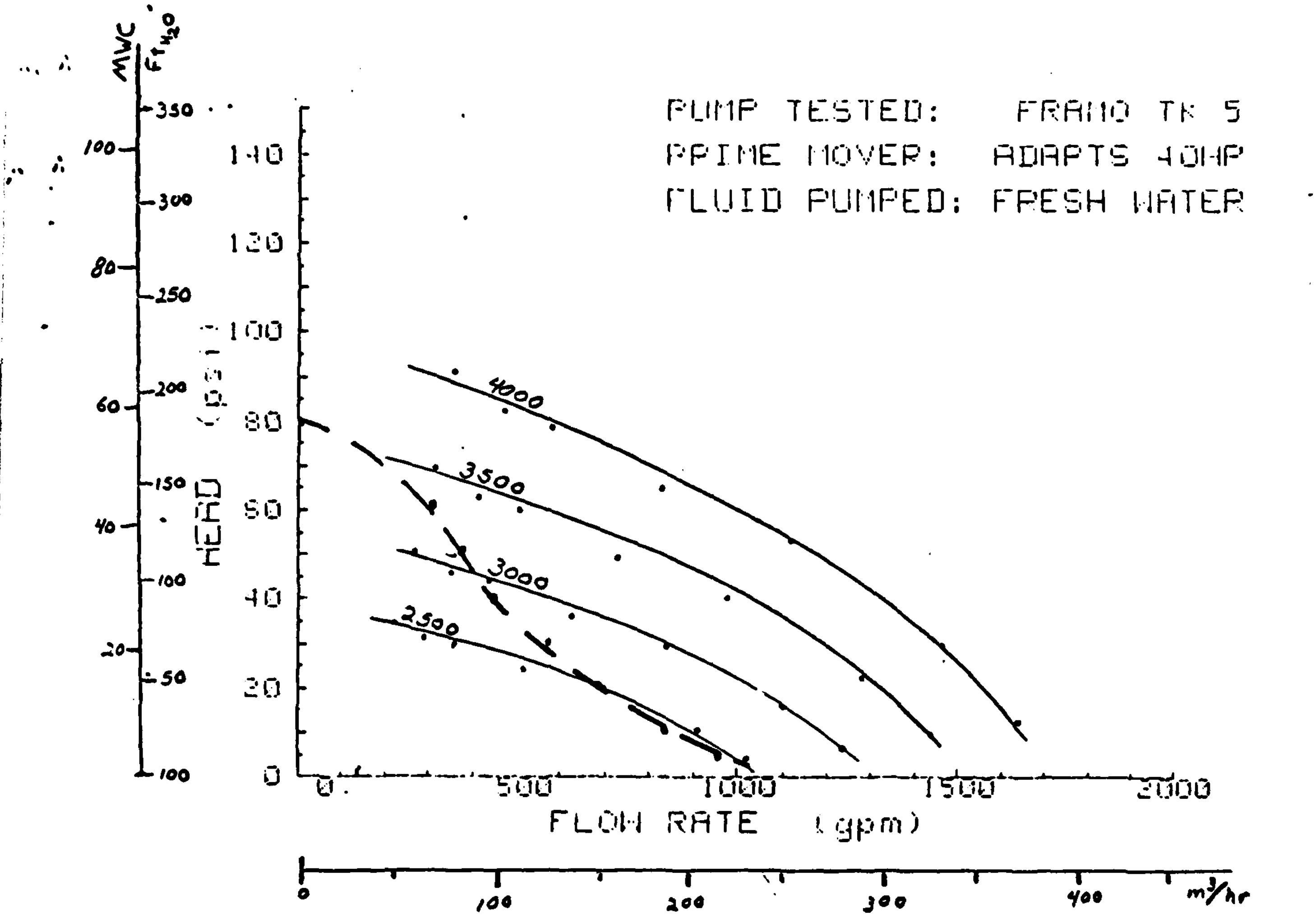

FIGURE 5

TEST			2500 RPM Qhydx 18.5		3000 RPM Qhydx 22.3		3500 RPM Qhydx 26.0		4000 RPM Qhydx 29.7	
Qhyd gpm	Qw gpm	Hp psi	Qwx gpm	Hpx psi	Qwx gpm	Hpx psi	Qwx gpm	Hpx psi	Qwx gpm	Hpx psi
17.0	942.2	4.5	1025.3	5.3	1235.9	7.7	1441.0	10.5	1646.1	13.7
17.0	838.7	10.0	912.7	11.8	1100.2	17.2	1282.7	23.4	1465.3	30.5
19.0	677.8	20.0	696.6	21.1	839.7	30.7	979.0	41.7	1118.4	54.5
20.0	551.2	30.0	519.1	25.7	625.7	37.3	729.6	50.7	833.4	66.2
21.0	412.1	40.0	363.0	31.0	437.6	45.1	510.2	61.8	582.8	80.0
23.0	306.9	50.0	295.1	32.3	355.7	47.0	414.8	63.9	473.8	83.4
24.0	290.3	60.0	224.2	35.7	270.3	51.8	315.1	70.4	360.0	91.9

SHUT OFF HEAD 80psi

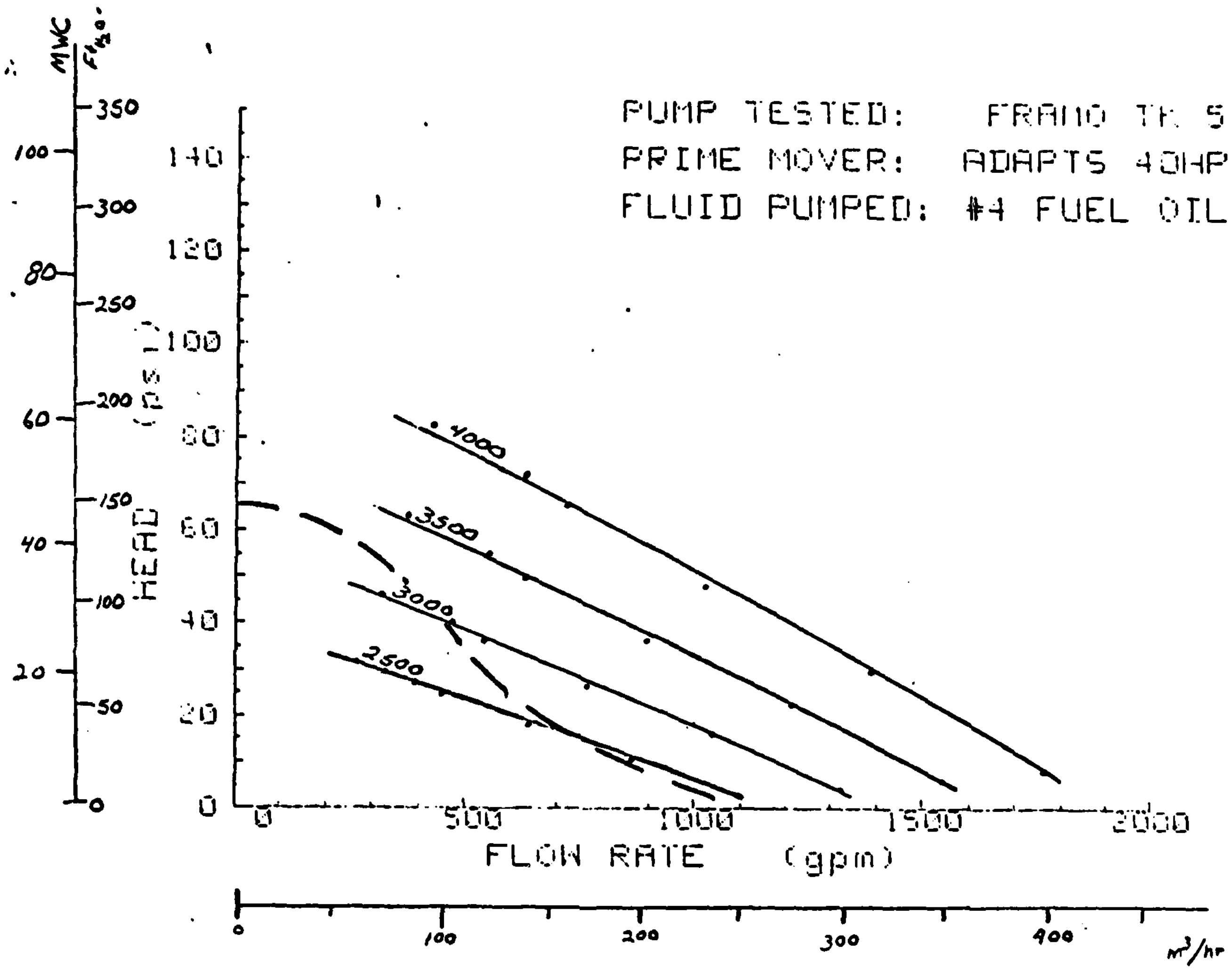

FIGURE 6

TEST	— — —		2500 RPM Qhydx 18.5		3000 RPM Qhydx 22.3		3500 RPM Qhydx 26.0		4000 RPM Qhydx 29.7	
[illegible] gpm	Qw gpm	Hp psi	Qwx gpm	Hpx psi	Qwx gpm	Hpx psi	Qwx gpm	Hpx psi	Qwx gpm	Hpx psi
17.0	1009.7	3.0	1098.8	3.6	1324.5	5.2	1544.2	7.0	1764.0	9.2
17.0	795.0	10.0	865.1	11.8	1042.9	17.2	1215.9	23.4	1388.9	30.5
19.0	655.9	20.0	638.6	19.0	769.8	27.6	897.5	37.5	1025.3	48.9
20.0	487.3	30.0	450.8	25.7	543.3	37.3	633.5	50.7	723.6	66.2
22.0	469.1	40.0	394.5	28.3	475.5	41.1	554.4	55.9	633.3	72.9
23.0	333.9	50.0	268.6	32.3	323.7	47.0	377.5	63.9	431.2	83.4

SHUT OFF HEAD 65psi

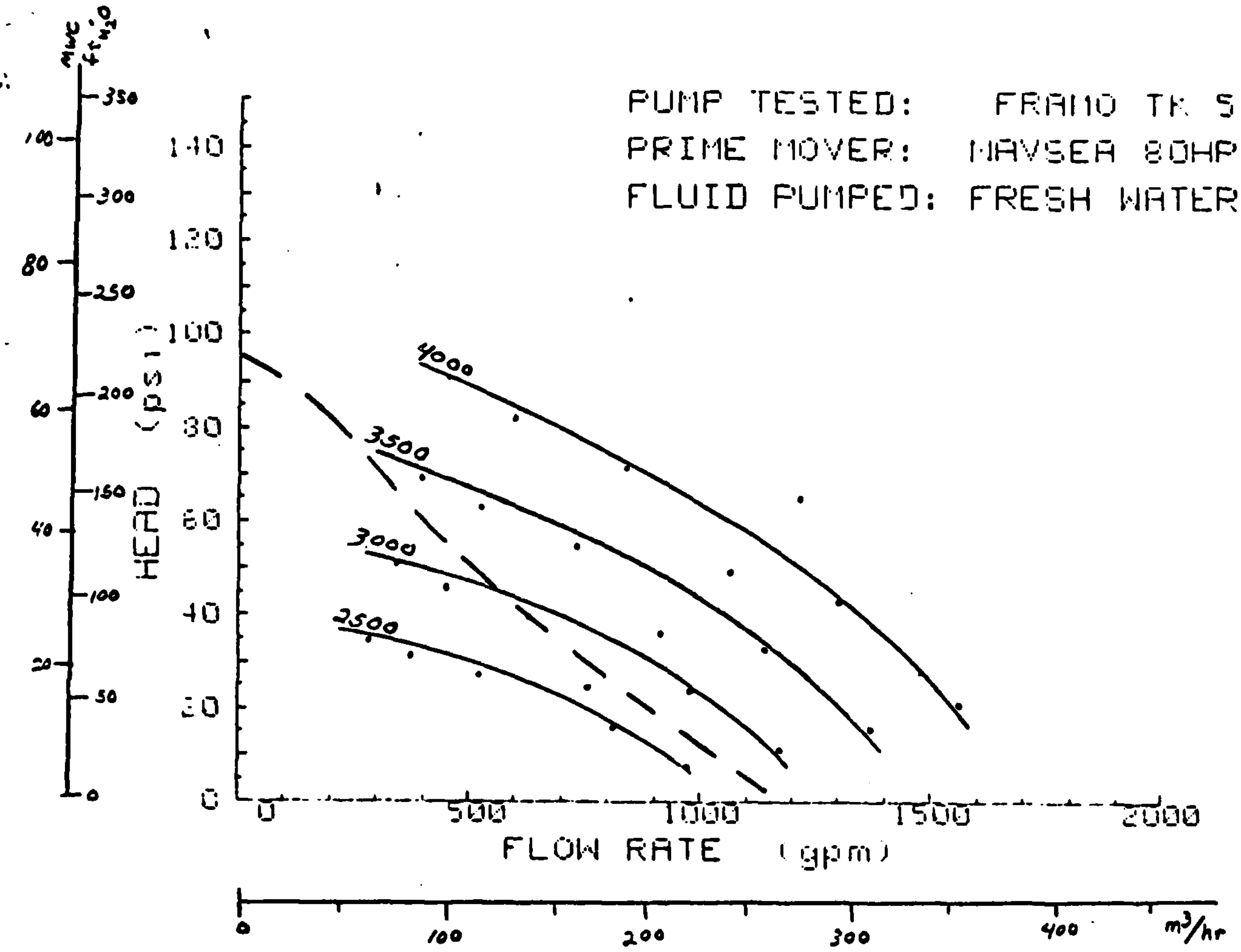

FIGURE 7

TEST			2500 RPM Qhydx 18.5		3000 RPM Qhydx 22.3		3500 RPM Qhydx 26.0		4000 RPM Qhydx 29.7	
Qhyd gpm	Qw gpm	Hp psi	Qwx gpm	Hpx psi	Qwx gpm	Hpx psi	Qwx gpm	Hpx psi	Qwx gpm	Hp psi
19.0	1054.1	10.0	975.0	8.6	1175.3	12.4	1370.3	16.9	1565.3	22.1
20.0	877.2	20.0	811.4	17.1	978.1	24.9	1140.4	33.8	1302.6	44.1
20.0	820.2	30.0	758.7	25.7	914.5	37.3	1066.3	50.7	1218.0	66.2
22.0	622.3	40.0	523.3	28.3	630.8	41.1	735.4	55.9	840.1	72.9
23.0	466.0	50.0	374.8	32.3	451.8	47.0	526.8	63.9	601.7	83.4
24.0	367.8	60.0	283.5	35.7	341.7	51.8	398.4	70.4	455.2	91.9

SHUT OFF HEAD 97psi

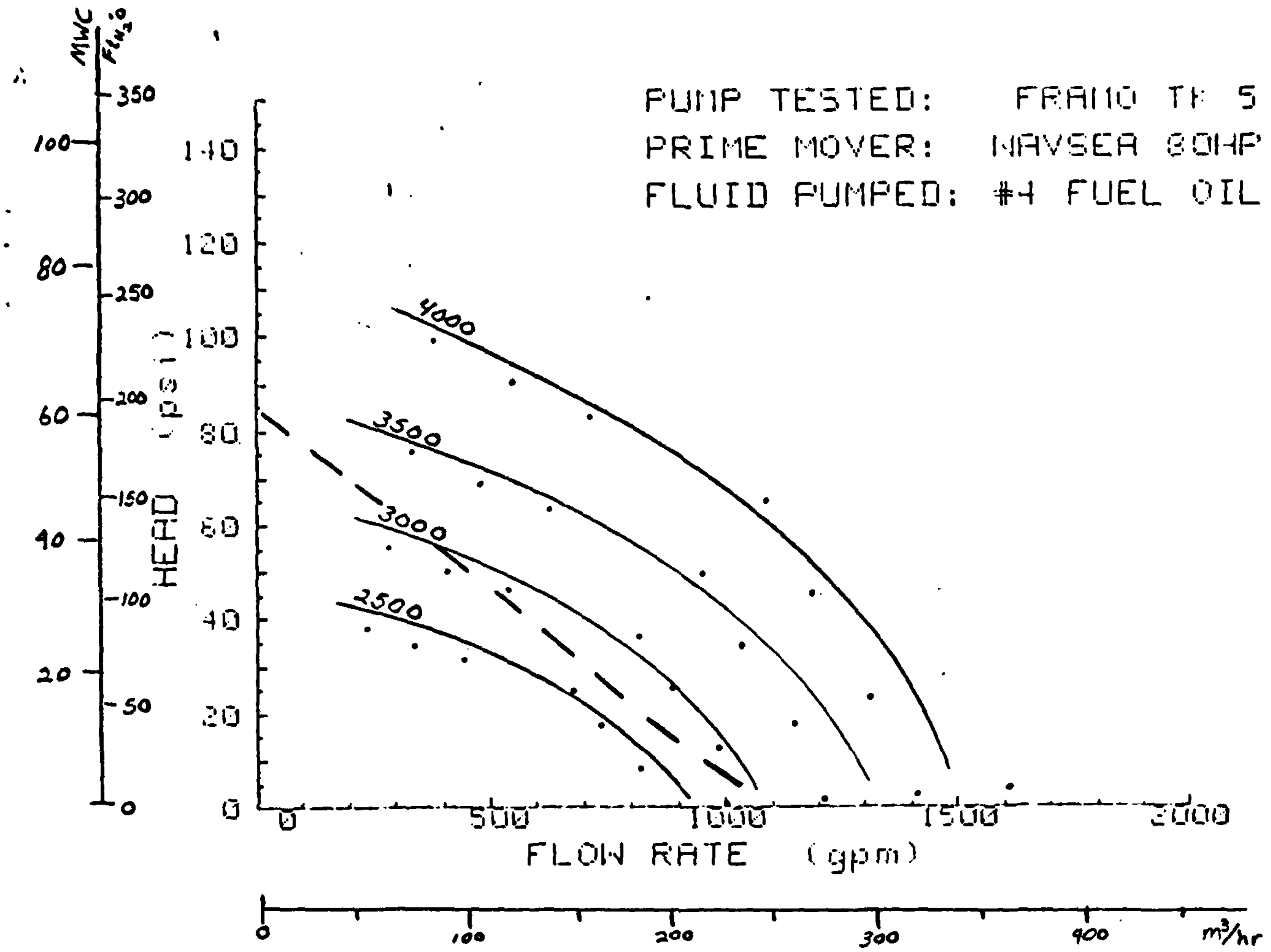

FIGURE 8

TEST			2500 RPM Qhydx 18.5		3000 RPM Qhydx 22.3		3500 RPM Qhydx 26.0		4000 RPM Qhydx 29.7	
Qhyd gpm	Qw gpm	Hp psi	Qwx gpm	Hpx psi	Qwx gpm	Hpx psi	Qwx gpm	Hpx psi	Qwx gpm	Hpx psi
19.0	1033.5	2.0	1006.3	1.9	1213.0	2.8	1414.3	3.7	1615.5	4.9
19.0	842.7	10.0	820.5	9.5	989.1	13.8	1153.2	18.7	1317.3	24.4
19.5	779.1	20.0	739.1	18.0	891.0	26.2	1038.8	35.6	1186.6	46.4
20.0	725.4	30.0	680.2	25.7	820.0	37.3	956.0	50.7	1092.1	66.2
20.5	496.9	40.0	448.4	32.6	540.5	47.3	630.2	64.3	719.9	84.0
22.0	407.8	50.0	342.9	35.4	413.4	51.4	481.9	69.8	550.5	91.1
23.0	298.1	60.0	239.8	38.8	289.0	56.4	337.0	76.7	384.9	100.0

SHUT OFF HEAD 85psi

6

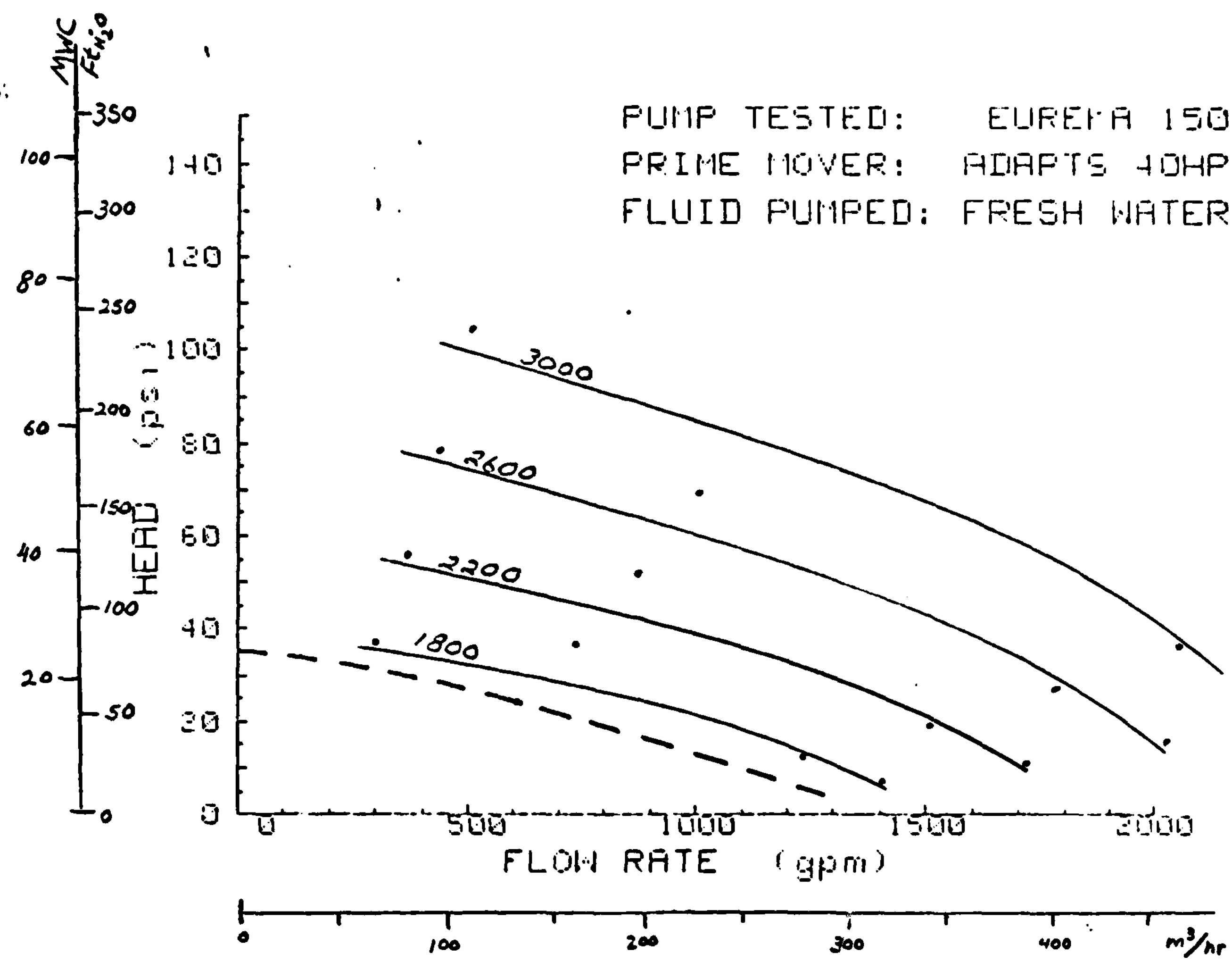

FIGURE 9

TEST			1800 RPM Qhydx 33.8		2200 RPM Qhydx 41.3		2600 RPM Qhydx 48.8		3000 RPM Qhydx 56.3	
Qhyd gpm	Qw gpm	Hp psi	Qwx gpm	Hpx psi	Qwx gpm	Hpx psi	Qwx gpm	Hpx psi	Qwx gpm	Hpx psi
29.0	1207.6	6.0	1407.5	8.2	1719.8	12.2	2032.1	17.0	2344.4	22.6
29.0	1060.0	10.0	1235.4	13.6	1509.6	20.3	1783.7	28.3	2057.9	37.7
30.0	537.5	20.0	605.6	25.4	740.0	37.9	874.3	52.9	1008.7	70.4
30.0	270.6	30.0	304.9	38.1	372.5	56.9	440.2	79.4	507.8	105.7

SHUT OFF HEAD 35psi

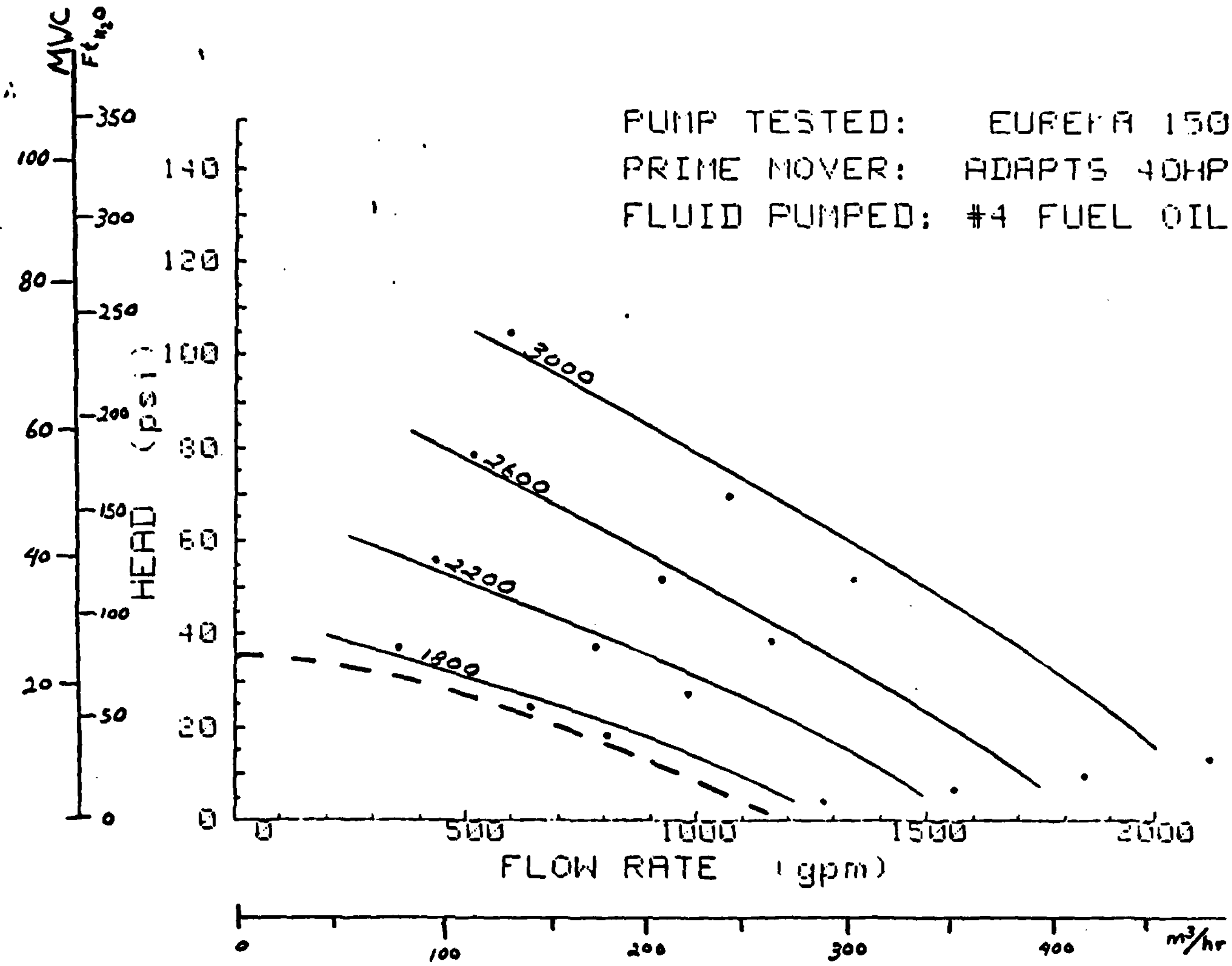

FIGURE 10

TEST			1800 RPM Qhydx 33.8		2200 RPM Qhydx 41.3		2600 RPM Qhydx 48.8		3000 RPM Qhydx 56.3	
Qhyd gpm	Qw gpm	Hp psi	Qwx gpm	Hpx psi	Qwx gpm	Hpx psi	Qwx gpm	Hpx psi	Qwx gpm	Hpx psi
30.0	1132.9	4.0	1276.4	5.1	1559.6	7.6	1842.9	10.6	2126.1	14.1
30.0	715.5	15.0	806.1	19.0	985.0	28.4	1163.9	39.7	1342.8	52.8
30.0	569.8	20.0	642.0	25.4	784.4	37.9	926.9	52.9	1069.3	70.4
30.0	318.0	30.0	358.3	38.1	437.8	56.9	517.3	79.4	596.8	105.7

SHUT OFF HEAD 35psi

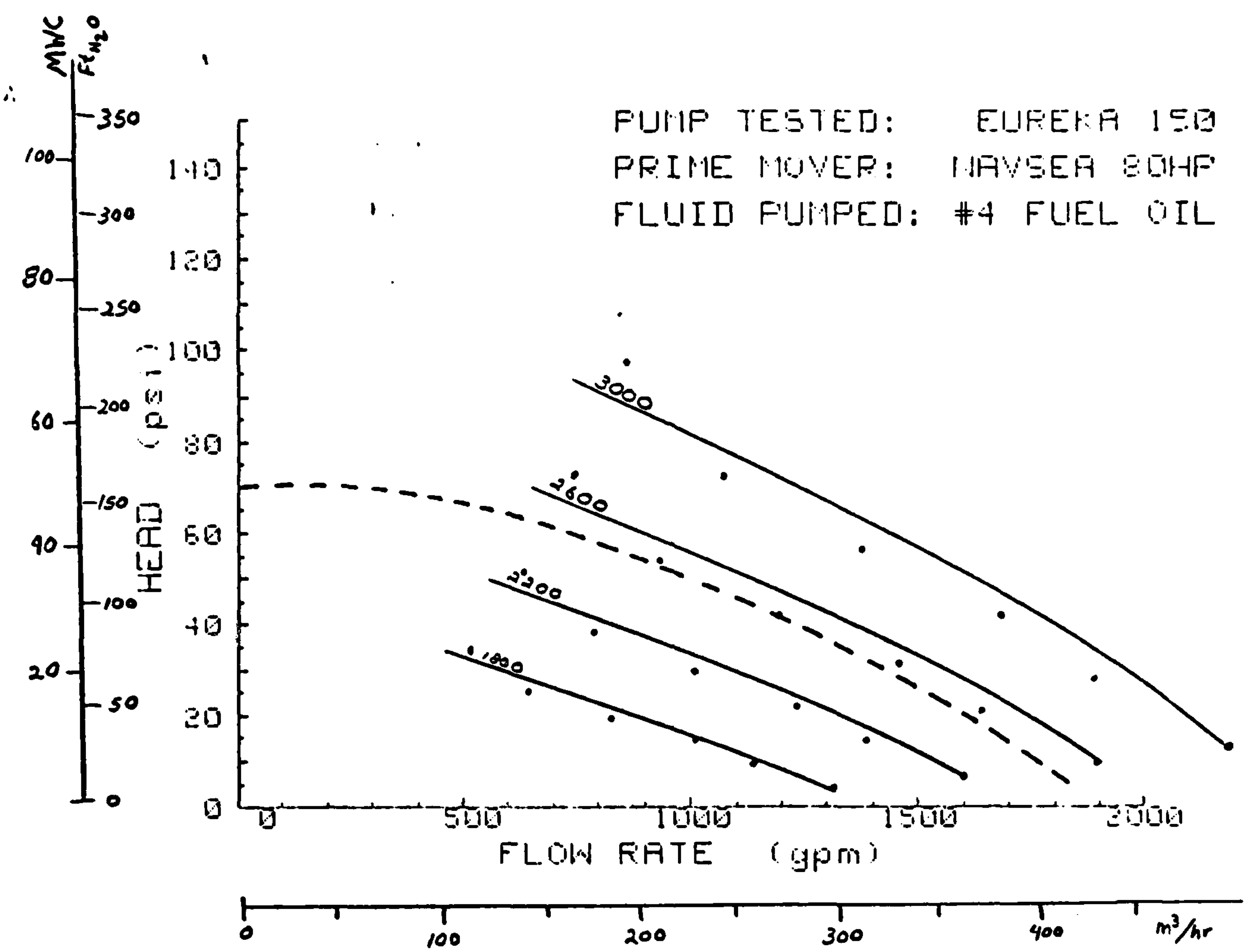

FIGURE 11

TEST			1800 RPM Qhydx 33.8		2200 RPM Qhydx 41.3		2600 RPM Qhydx 48.8		3000 RPM Qhyd. 56.3	
Qhyd gpm	Qw gpm	Hp psi	Qwx gpm	Hpx psi	Qwx gpm	Hpx psi	Qwx gpm	Hpx psi	Qwx gpm	Hpx psi
47.0	1828.5	10.0	1315.0	5.2	1606.7	7.7	1898.5	10.8	2190.3	14.3
45.5	1566.2	20.0	1138.4	10.6	1391.1	15.8	1643.7	22.0	1896.3	29.3
47.0	1407.2	30.0	1012.0	15.5	1236.5	23.2	1461.0	32.3	1685.6	43.0
47.0	1152.8	40.0	829.0	20.7	1012.9	30.9	1196.9	43.1	1380.8	57.4
46.5	890.4	50.0	647.2	26.4	790.8	39.4	934.4	55.1	1078.1	73.3
44.0	675.8	60.0	519.1	35.4	634.3	52.9	749.5	73.8	864.7	98.2

SHUT OFF HEAD 70psi

5.0 DISCUSSION

5.1 Pump Performance

Most of the pump characteristic curves display the normal operating characteristics of a centrifugal pump. In almost all instances, the performance of the pump tested was less than the pump manufacturer had specified. The pump characteristic curves in Figures 12 and 13 show the comparison between the manufacturer's specifications and the test results. The difference in the pump characteristic curves could be due to any of the following reasons:

1. The limitations on the volume of fluid available to pump for a continuous test caused tight time limitations for each test. The time limitations did not allow the whole system to completely reach steady state operation prior to the monitoring at each test point. This error is not expected to be greater than 5% for any parameter monitored.

2. The accuracy of the parameter monitoring instruments used and the accuracy of the person reading the instrument would constitute some error. The worst expected error from the instrument readings is as follows:

Instrument	Worst Expected Error
pressure gauges	$\pm$ 2%
hydraulic flow meter	$\pm$ 1 gpm
tank level (float meter)	$\pm$ ¼ in. *
temperature	$\pm$ 1°F

The combined effect of these possible errors account for the majority of the differences between the manufacturer and the test results. The method used in correcting the raw data to a constant pump speed causes an amplification of the error. The greater the difference between the test speed and the pump speed desired, the larger the effect of the error.

* The tank level error represents about 25 gpm error in the flow rate of the fluid pumped.

COMPARISON OF PUMP CHARACTERISTIC CURVES
MANUFACTURER AND TEST RESULTS

PUMP: FRAMO TK-5
FLUID PUMPED: WATER
PUMP SPEED: 3000 RPM

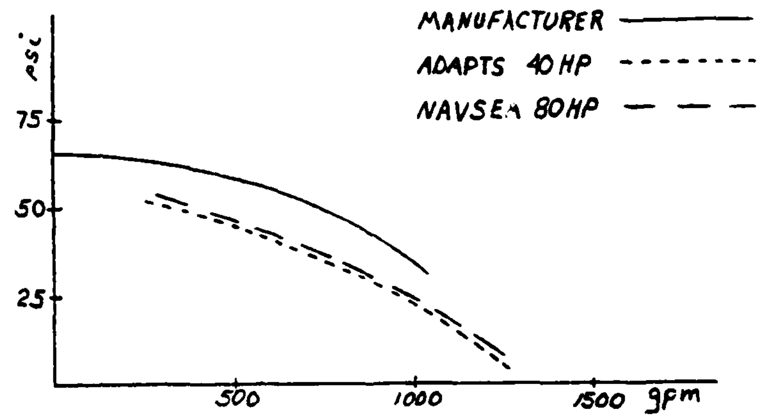

FIGURE 12

PUMP: EUREKA 150
FLUID PUMPED: WATER
PUMP SPEED: 2600 RPM

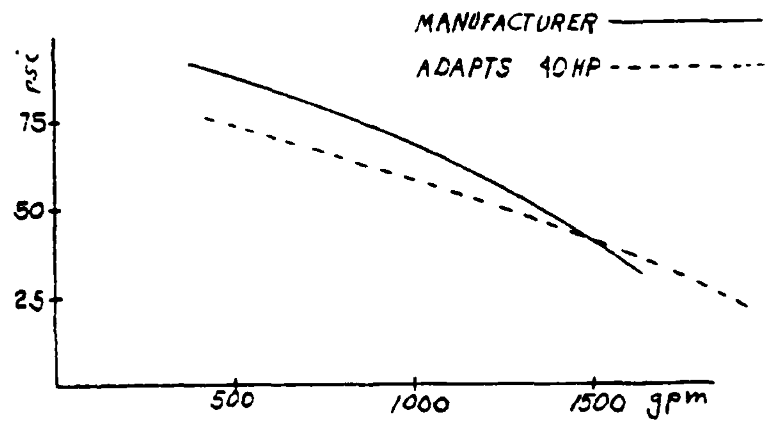

FIGURE 13

3. The assumptions made in the calculation of the parameters used to evaluate the pump performance are valid within the accuracy of the monitoring instruments. A correction for the static pressure loss in the pressure sensing lines was not included in the calculations. It was felt that this would yield conservative results from the test. (Actual pressure did not exceed the recorded gauge pressure plus 3 psi.) This amount was relatively constant throughout the testing and therefore does not affect the comparison of the pump results. It is believed that this error is not significant within the scope of the pump tests.

5.2 Pumping System Performance

When evaluating the performance of a pump, it is necessary to consider the intended use of the pump as well as the operational limitations imposed on the pump. This immediately imposes a restriction on the area of the pump performance curve which is applicable for consideration.

Besides the limitations the hydraulic prime mover places on the pump performance (section 4.2), the operation point of the pump is determined by the restrictions of the pumping system, namely head loss. The system head loss consists of two major components, the static head loss and the dynamic head loss. The static head loss is the pressure loss due to the distance the pump must move the fluid vertically. For example, if the fluid is moved vertically 12 feet, there would be a static head loss of about 5 psi. The dynamic head loss is due to the frictional forces as the fluid flows along the pipe (or hose). The previous Framo TK-4 pump test determined the expected dynamic head losses for 100 feet of 4-inch corrugated stainless steel hose (corrugation pitch = 0.231 in) by using the fluid expansion theory.[3] For simplicity, the previous test did not account for the losses due to the fittings and bends, both of which would increase the flow losses.

The summation of the losses allows a curve to be constructed which would be representative of the expected system head loss. This curve is called the system characteristic curve. The point where the pump performance curve intersects the intended system characteristic curve would be the operating point of the pump in the given system.

Figures 14 through 16 allow a comparison of expected operating points for various pumps. The pump performance curves used in this comparison are from the test results which include the performance limitations imposed by the hydraulic prime mover. The prime mover and fluid being pumped is indicated above the figure and each respective pump performance curve is labeled. The system characteristic curve used for the comparison results from a test set-up consisting of a 12-foot vertical rise and 100 feet of 4-inch corrugated stainless steel discharge hose (see appendix C-1 for derivation of system equation). This was considered to be a minimal system; bends, increased discharge hose, and fittings would increase the rate at which the head loss is increasing. This would in turn move the operating point to a higher pump discharge pressure and lower flow rate.

It can be seen from figure 14 and figure 15 that with the ADAPTS 40 HP prime mover, pumping either fresh water or number 4 fuel oil (110-120cS), the Framo TK-5 provides about twice the discharge flow as can be provided by the Framo TK-4. This implies that the potential pumping time can be cut in half under the specified conditions by using the TK-5 as opposed to the TK-4.

Comparing figure 15 and figure 16 it can be seen that with a single Framo TK-5 there is little advantage in using the larger NAVSEA prime mover. However, the tests indicated that the larger prime mover has the capacity to provide sufficient hydraulic flow to operate two Framo TK-5 pumps in parallel. This would not only double the pumping flow rate but also, 1) increase the system reliability, and 2) allow simultaneous offloading of two cargo holds so as to minimize the listing of the stricken vessel. Of course, these advantages could also be accomplished by having two ADAPTS prime movers on scene, which would further increase the overall reliability.

5.3 Physical Characteristics of the Pumps and Prime Movers

The Framo TK-4 and TK-5 pumps are all stainless steel pumps. The seal materials are Teflon in the TK-4 and TK-5. The combination of these materials of construction make the Framo pumps an excellent choice for a hazardous chemical offloading pump. The Eureka 150 pump is of nickel-aluminum-bronze construction and uses Teflon and Viton seals in areas exposed to the cargo. It can also be made in stainless steel to provide the necessary chemical resistance to hazardous chemicals.

The weights of these pumps as tested are:

Framo TK-4	175 lbs.
Framo TK-5	177 lbs.
Eureka 150	287 lbs.

The Framo pumps were all easily handled by two men while the Eureka 150 required four men due to handle positioning and weight.

The ADAPTS prime mover consists of two components, the prime mover and the fuel module. The prime mover weighs 1150 lbs. and measures 44" x 34" x 41". The fuel module measures 23-1/2" in diameter and 34-1/2" in length when filled. Its filled weight is 440 lbs. giving a total system weight of 1590 lbs. The ADAPTS prime mover has a protective enclosure, a definite advantage considering its intended delivery mode.

The NAVSEA prime mover, which does not have an enclosure like the ADAPTS, is a single unit. The unit has a fuel tank as part of the prime mover. The NAVSEA prime mover measures 54" x 32" x 96" and weights 3800 lbs., more than twice that of the ADAPTS.

COMPARISON OF POTENTIAL OPERATING POINTS

PRIME MOVER: ADAPTS 40 HP
FLUID PUMPED: FRESH WATER

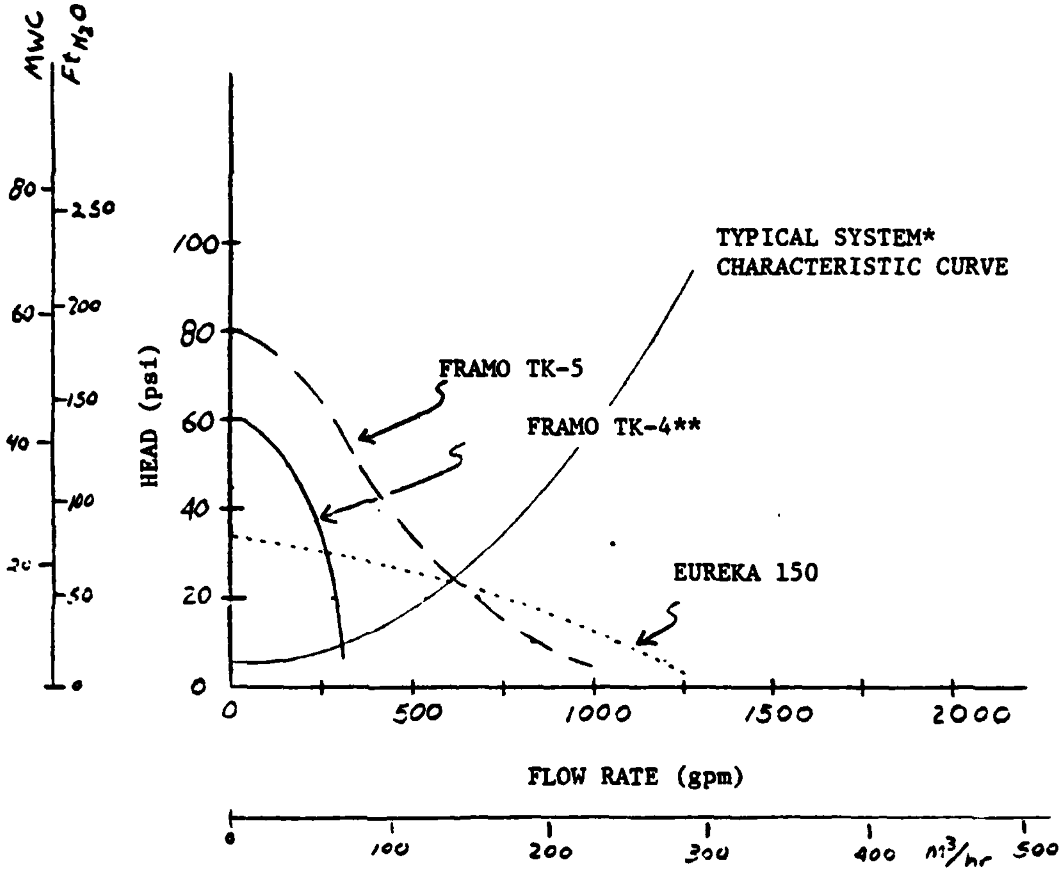

FIGURE 14

*System consists of a 12-foot static head and 100 feet 4-inch corrugated stainless steel discharge hose.

**Framo TK-4 with vickers 25M42A 1C20 hydraulic motor data from previous pump test

COMPARISON OF POTE\TIAL OPERATING POINTS

PRIME MOVER: ADAPTS 40 HP
FLUID PUMPED: #4 FUEL OIL (110-120 cS)

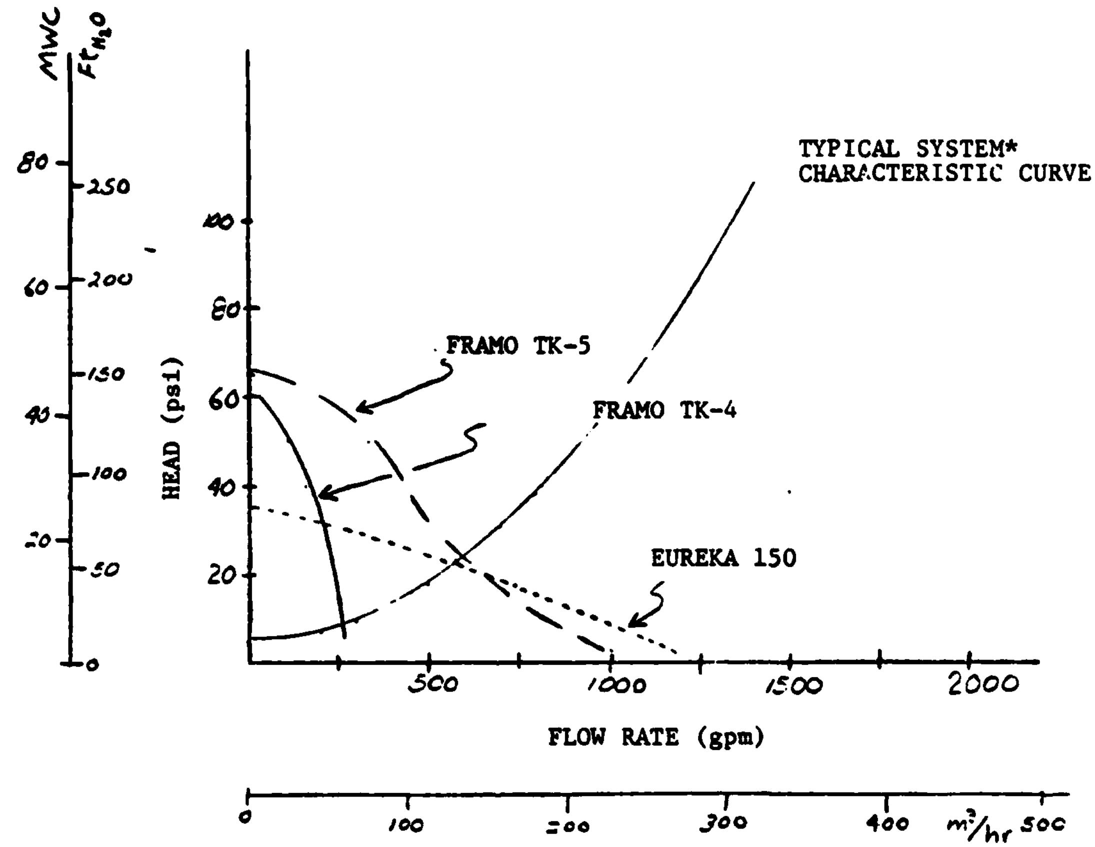

FIGURE 15

*System consists of a 12-foot static head and 100 feet 4-inch corrugated stainless steel discharge hose.

**Framo TK-4 with vickers 25M42A 1C20 hydraulic motor data from previous pump test.

COMPARISON OF POTENTIAL OPERATING POINTS

PRIME MOVER: NAVSEA 80 HP
FLUID PUMPED: #4 FUEL OIL (110-120 cS)

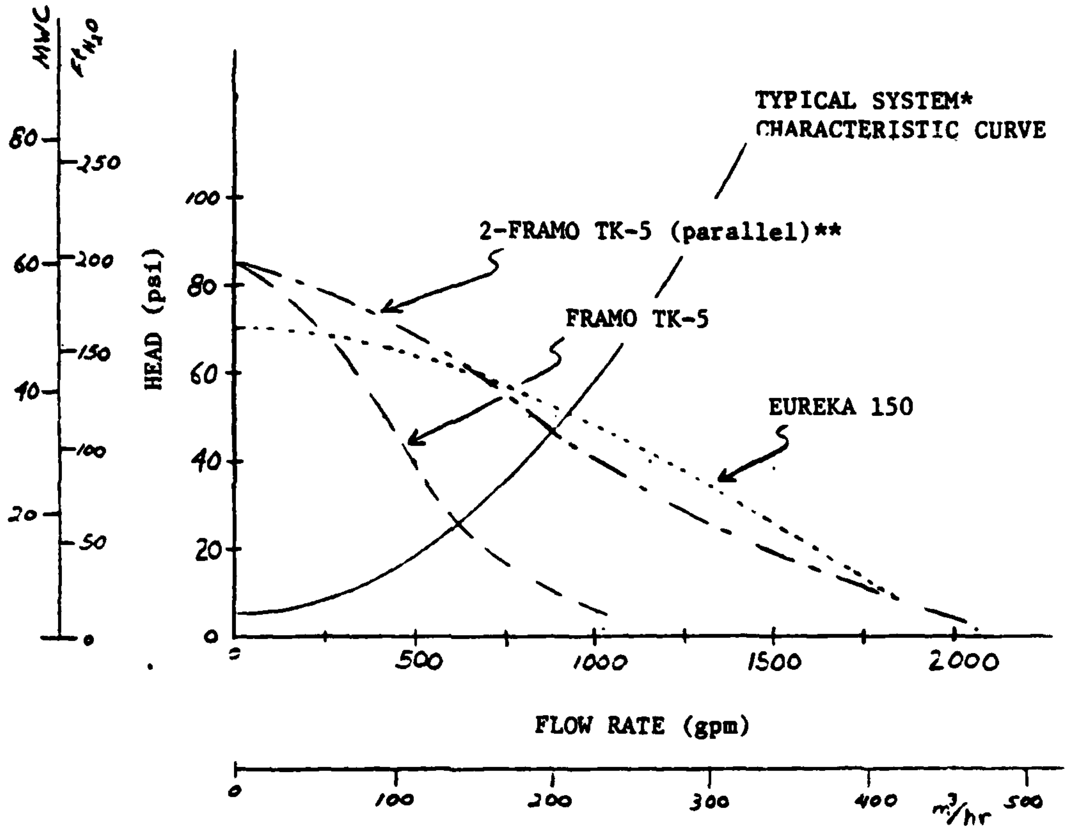

FIGURE 16

*System consists of a 12-foot static head and 100 feet 4-inch corrugated stainless steel discharge hose.

**NAVSEA 80 HP prime mover has capability to operate two (2) Framo TK-5 pumps simultaneously.

6.0 CONCLUSIONS

From the results of this pump test, the following conclusions can be made.

1. The Framo TK-5 can provide a greater discharge flow rate than the Framo TK-4 under the same test conditions.

2. The Framo TK-5 performed well with the ADAPTS prime mover.

3. Both the Framo TK-5 and the Thune-Eureka 150 pumps performed well with the NAVSEA prime mover.

4. The NAVSEA prime mover has the capability to operate two Framo TK-5 pumps simultaneously.

REFERENCES

1. Hydraulic Institute Standards, Hydraulic Institute Standards for Centrifugal, Rotary & Reciprocating Pumps. 13th ed., Cleveland, Ohio: Hydraulic Institute Standards, 1975.

2. Framo TK-4 Pump Test. Groton, Connecticut: USCG Research and Development Center, 1977.

3. Hawthorne, R.C., "Flow in Corrugated Hose." Product Engineering, June 10, 1963, p. 98-100.

4. Karassik, I.J., Pump Handbook. New York: McGraw-Hill Book Co., 1976.

APPENDIX A

FUEL OIL VISCOSITIES

TEST FLUID PROPERTIES

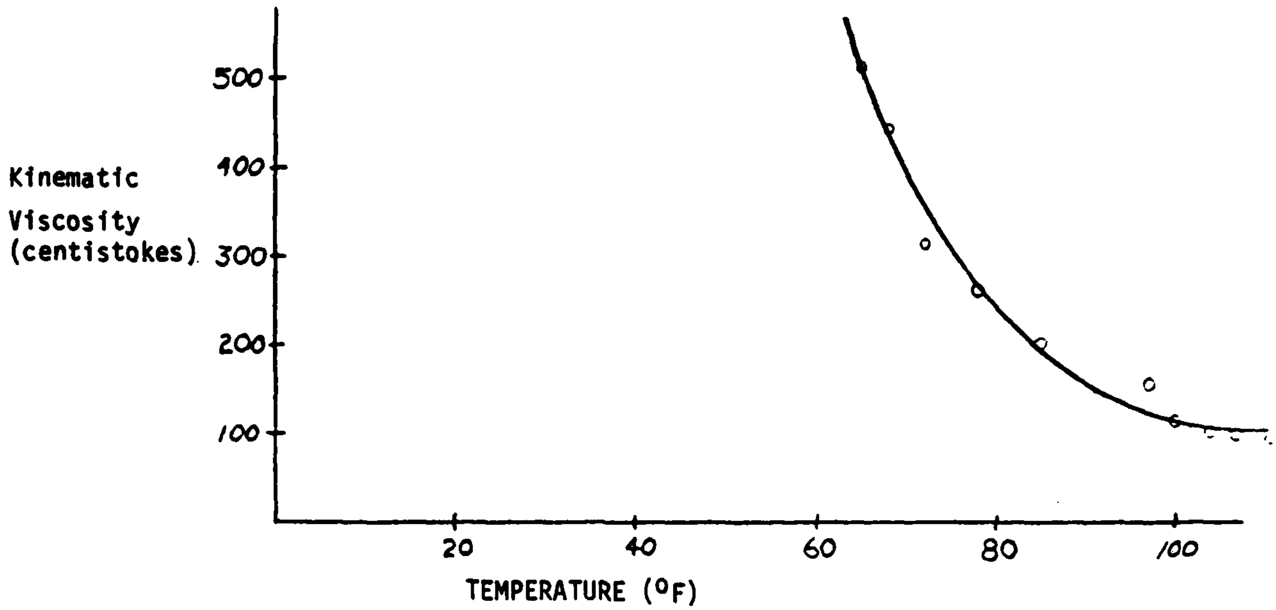

FIGURE A-1

NO. 4 FUEL OIL VISCOSITY GRAPH

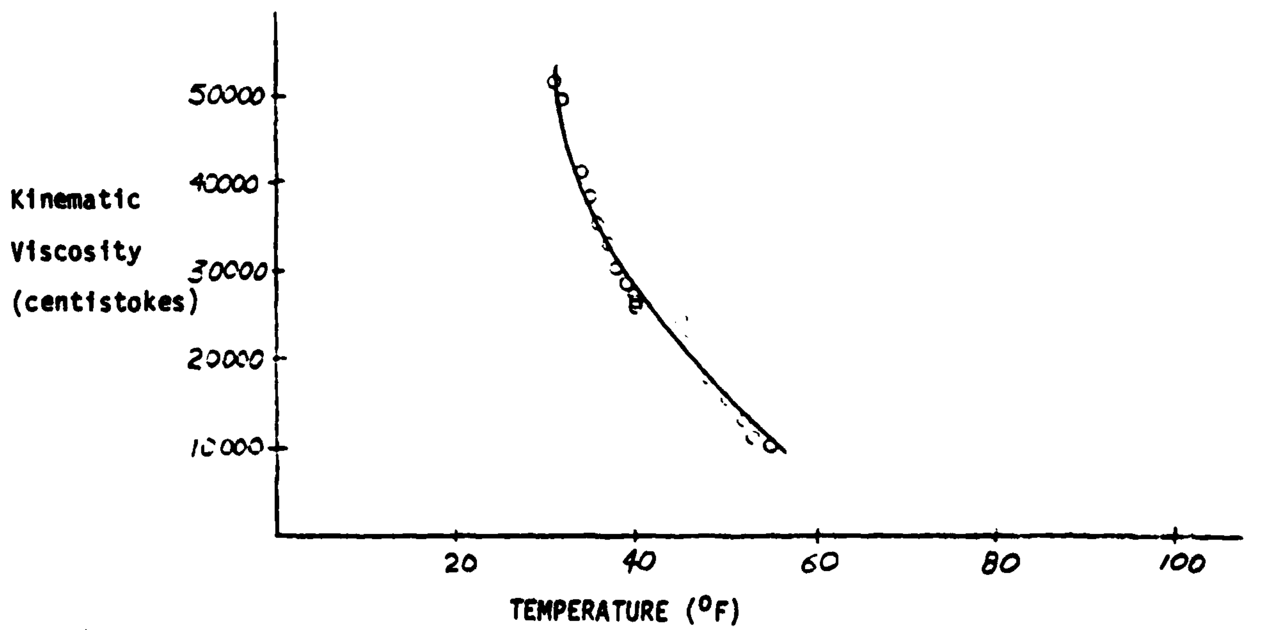

FIGURE A-2

NO. 6 FUEL OIL VISCOSITY GRAPH

APPENDIX B

RAW TEST DATA

TABLE B-1

PUMP TESTED: FRAMO TK-4
HYDRAULIC PRIME MOVER: NAVSEA 80 HP
FLUID PUMPED: Fresh Water

	HYDRAULIC SYSTEM				PUMP			
ENGINE SPEED (RPM)	TEMP OIL (^oF)	PRESS SUPPLY (psi)	PRESS RETURN (psi)	FLOW RATE (GPM)	HEAD (psi)	# INCHES PUMPED (in)	TIME (min)	FLUID TEMP (^oF)
2000	100	2100	45	40	27	6.125	2.90	52
1900	100	2065	41	40	30	6.190	2.98	52
1900	100	2020	40	40	40	6.060	3.22	52
1880	100	1880	39	40	50	6.000	3.83	52
1880	100	1700	39	40	60	6.090	4.88	52
1800	100	1200	40	40	75	2.940	5.87	52

SHUT OFF HEAD 95 psi

TABLE B-2

PUMP TESTED: FRAMO TK-5
HYDRAULIC PRIME MOVER: ADAPTS 40 HP
FLUID PUMPED: Fresh Water

	HYDRAULIC SYSTEM				PUMP			
ENGINE SPEED (RPM)	TEMP ENG (^oF)	PRESS SUPPLY (psi)	PRESS RETURN (psi)	FLOW RATE (GPM)	HEAD (psi)	# INCHES PUMPED (in)	TIME (min)	FLUID TEMP (^oF)
2800	170	2000	60	17	4.5	12	4.05	52
2800	190	2000	55	17	10.0	12	4.55	52
2800	215	2000	50	18	20.0	12	5.63	52
2775	215	2000	50	20	30.0	6	3.40	52
2750	185	2000	50	21	40.0	6	4.63	52
2800	205	2000	50	23	50.0	6	5.20	52
2775	225	2000	40	24	60.0	3	3.28	52

SHUT OFF HEAD 80 psi

TABLE B-3

PUMP TESTED: FRAMO TK-5
HYDRAULIC PRIME MOVER: NAVSEA 80 HP
FLUID PUMPED: Fresh Water

	HYDRAULIC SYSTEM				PUMP			
ENGINE SPEED (RPM)	TEMP OIL (°F)	PRESS SUPPLY (psi)	PRESS RETURN (psi)	FLOW RATE (GPM)	HEAD (psi)	# INCHES PUMPED (in)	TIME (min)	FLUID TEMP (°F)
1150	100	2440	29.0	20	10	12.000	3.62	52
1150	100	2420	28.5	20	20	12.000	4.35	52
1100	85	2400	32.0	20	30	6.500	2.52	52
1150	90	2420	33.0	22	40	6.125	3.13	52
1250	90	2400	34.0	23	50	6.125	4.18	52
1250	90	2400	35.0	24	60	5.875	5.08	52

SHUT OFF HEAD 97 psi

TABLE B-4

PUMP TESTED: FRAMO TK-5
HYDRAULIC PRIME MOVER: ADAPTS 40 HP
FLUID PUMPED: #4 Fuel Oil

	HYDRAULIC SYSTEM				PUMP			
ENGINE SPEED (RPM)	TEMP ENG (°F)	PRESS SUPPLY (psi)	PRESS RETURN (psi)	FLOW RATE (GPM)	HEAD (psi)	# INCHES PUMPED (in)	TIME (min)	FLUID TEMP (°F)
2800	239	2150	70	17	3	6.35	2	107.5
2825	237	2150	65	17	10	10.00	4	107.5
2800	237	2100	70	19	20	8.25	4	107.5
2800	232	2100	75	20	30	6.13	4	107.0
2775	225	2150	75	22	40	5.90	4	107.0
2725	195	2150	80	23	50	4.20	4	107.25

SHUT OFF HEAD 65 psi

TABLE B-5

PUMP TESTED: FRAMO TK-5
HYDRAULIC PRIME MOVER: NAVSEA 80 HP
FLUID PUMPED: #4 Fuel Oil

ENGINE SPEED (RPM)	HYDRAULIC SYSTEM TEMP OIL (°F)	HYDRAULIC SYSTEM PRESS SUPPLY (psi)	HYDRAULIC SYSTEM PRESS RETURN (psi)	HYDRAULIC SYSTEM FLOW RATE (GPM)	PUMP HEAD (psi)	PUMP # INCHES PUMPED (in)	PUMP TIME (min)	FLUID TEMP (°F)
1100	102	2450	40	19.0	2	6.50	2	108.0
1100	102	2450	40	19.0	10	5.30	2	107.3
1100	102	2450	42	19.5	20	9.80	4	106.7
1120	100	2450	45	20.0	30	9.25	4	106.5
1190	100	2450	50	20.5	40	7.25	4	106.0
1200	90	2450	55	22.0	50	5.13	4	106.0
1220	80	2450	65	23.0	60	3.75	4	106.0

SHUT OFF HEAD 85 psi

TABLE B-6

PUMP TESTED: EUREKA 150
HYDRAULIC PRIME MOVER: ADAPTS 40 HP
FLUID PUMPED: Fresh Water

ENGINE SPEED (RPM)	HYDRAULIC SYSTEM TEMP ENG (°F)	HYDRAULIC SYSTEM PRESS SUPPLY (psi)	HYDRAULIC SYSTEM PRESS RETURN (psi)	HYDRAULIC SYSTEM FLOW RATE (GPM)	PUMP HEAD (psi)	PUMP # INCHES PUMPED (in)	PUMP TIME (min)	FLUID TEMP (°F)
2820		1000	60	29	6	6	1.58	52
2800		1000	60	29	10	6	1.80	52
2820		1000	60	30	29	6	3.55	52
2800		1200	80	30	30	6	7.05	52

SHUT OFF HEAD 35 psi

TABLE B-7

PUMP TESTED: EUREKA 150
HYDRAULIC PRIME MOVER: ADAPTS 40 HP
FLUID PUMPED: #4 Fuel Oil

	HYDRAULIC SYSTEM				PUMP			
ENGINE SPEED (RPM)	TEMP ENG (^oF)	PRESS SUPPLY (psi)	PRESS RETURN (psi)	FLOW RATE (GPM)	HEAD (psi)	# INCHES PUMPED (in)	TIME (min)	FLUID TEMP (^oF)
2800	128	1325	200	30	4	14.25	4	106
2800	122	1300	205	30	15	9.00	4	106
2800	117	1300	200	30	20	10.75	6	106
2800	110	1400	230	30	30	4.00	4	106

SHUT OFF HEAD 35 psi

TABLE B-8

PUMP TESTED: EUREKA 150
HYDRAULIC PRIME MOVER: NAVSEA 80 HP
FLUID PUMPED: #4 Fuel Oil

	HYDRAULIC SYSTEM				PUMP			
ENGINE SPEED (RPM)	TEMP OIL (^oF)	PRESS SUPPLY (psi)	PRESS RETURN (psi)	FLOW RATE (GPM)	HEAD (psi)	# INCHES PUMPED (in)	TIME (min)	FLUID TEMP (^oF)
2150	100	2450	80	47.0	10	11.50	2	106.0
2150	100	2450	80	46.5	20	9.85	2	105.0
2120	95	2450	90	47.0	30	8.85	2	104.5
2120	90	2425	90	47.0	40	7.25	2	104.5
2080	80	2450	100	46.5	50	11.20	4	104.5
2080	67	2425	100	44.0	60	8.50	4	104.0

SHUT OFF HEAD 70 psi

APPENDIX C

CORRUGATED HOSE FLOW CHARACTERISTICS

The fluid expansion theory was used to compute the head loss through the 4-inch corrugated stainless steel discharge hose. An explanation of the fluid expansion theory may be found in Product Engineering magazine (June 1963). All the equations used are extracted from the article, Flow in Corrugated Hose.

The fluid expansion theory assumes that the corrugations behave as a series of uniformly spaced orifices. This assumption allows the Darey-Weisbach resistance equation with the friction factor (f) a function of the corrugation spacing (pitch (s)), hose length (L), and hose inside diameter (D) to be used in calculating the pressure loss. The following relationships exist.

$$P = f \frac{L}{D} \left(\frac{V^2 \rho}{9266}\right)$$

and

$$f = \frac{L}{S} \left(1 - \left(\frac{D}{D + 0.4385}\right)^2\right)^2 \frac{D}{L}$$

where, P = the pressure loss (psi)
V = fluid velocity (fps)
ρ = fluid density (lb per cu. ft.)
and 9266 = unit conversion constant

Table D-1 lists the parameters which were set constant for the example case. Applying these constants and substituting the flow rate (Q) divided by the hose cross-sectional area (A) for the velocity (V) in the pressure loss equation the following relationships result;

For water $P = 5.426 \times 10^{-5} Q^2$
and #4 fuel oil $P = 5.155 \times 10^{-5} Q^2$

where P = the pressure loss (psi)
and Q = the fluid flow rate (gpm)

Table D-1

Parameter	Value
Length (L)	1200 in (100 ft)
Dia (D)	4 in
Pitch (S)	0.231 in/corrugation
Density (ρH_2O)	62.5 lb/ft^3
(ρ#4 F.O.)	56.25 lb/ft^3